10 Trade-off and opportunity mapping

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10.1 Introduction

Underlying ecological and environmental constraints for ecosystem services have resulted in their current complex spatial distribution in the Welsh landscape. Some services often co-exist as they require similar environmental conditions e.g. carbon storage and water regulation whilst other services are often negatively associated (agriculture production and water quality). The GMEP Year 1 report reported on an initial analysis of the data which highlighted how the GMEP data could be used to quantify these trade-offs and co-benefits. Agricultural productivity and carbon storage were identified to be positioned at different extremes of a gradient of from high to low land intensification with biodiversity often at its most species rich at intermediate levels as previously reported at the UK scale by Countryside Survey (Maskell et al. 2013; Emmett et al. 2014). In the future GMEP data will be used to explore these relationships at different scales and for different regions but there is a need now to provide a tool which can help policy makers and land managers target specific areas in the Welsh landscape where opportunities are greatest to increase ecosystem service provision with minimal trade-offs. We have exploited the LUCI modelling tool described in the GMEP Year 1 report to start this process.

10.2 Highlights from Year 2 and major findings

Calculations have been made on the spatial data to identify for each ecosystem service the total area with good provision, total area with opportunity to improve, and area with opportunity to improve without risk to existing services in good condition for Wales. Further calculations were then performed for each ecosystem service to identify where opportunities to improve ecosystem services coincide spatially with good existing condition for other ecosystem services. Finally, calculations were performed for each ecosystem service pair to identify where both have opportunities to improve.

- Significant areas have opportunity to improve carbon (C) status (10508km^2), however for the vast majority of these sites, there are other services in good condition, so care must be taken to avoid detrimental effects if options are targeted at improving C status. Many of these trade-offs are with priority habitats (7488 km^2) (largely heather dominated grasslands), agricultural utilisation (5424 km^2) areas reducing erosion risk (9693 km^2), and potential nitrogen (N) (7731 km^2) and phosphorus (P) (9834 km^2) loss to freshwaters. It is likely that changes to improve C status would not increase erosion risk, or potential N and P loss to freshwaters, however the need to protect priority habitats, and socioeconomic value of agricultural production may reduce potential to achieve carbon status improvements.
- Potential N loss to freshwaters has reasonable opportunities (104 km^2) to improve (reduce) without risk of damaging other ecosystem services (ES) or agricultural productivity. Significant proportions of the 5231 km^2 of sites with opportunity to improve (reduce) potential N loss to freshwaters also have opportunities to improve (reduce) potential P loss to freshwaters (1228 km^2), C status (2777 km^2), Broadleaved woodland habitat connectivity (1038 km^2) and mitigation of overland flow which may contribute to flood mitigation (3955 km^2).
- Over 321km^2 were classified as non-mitigated land in terms of runoff, and had no other ecosystem services in good condition, which may indicate significant potential for interventions to reduce flood risk, without damaging other ES or agricultural productivity. However, additional data to improve representation of soil drainage is being explored, and

depending on flow regimes not all non-mitigated features currently create flood risk, hence further assessment of these opportunities is necessary.

- Locations with low agricultural productivity that are not in good condition for other ES were mapped as over 97 km^2. Whilst there may be potential to increase agricultural productivity in these locations, land may be less suitable for agriculture, and interventions to improve other ES may be more appropriate.
- Calculations have been performed on all outputs to identify where there are trade-offs and win-wins across all 7 ecosystem services considered. 36 km^2 have opportunities to improve 6 of the 7 modelled ecosystem services; all of this area has opportunity to improve (reduce) N potential loss to freshwaters, whereas 16 km^2 have good existing provision of agricultural productivity. Looking at co-location of opportunities to improve ecosystem services for all 7 services indicates that ca. 10% has existing multiple service provision whilst almost 28% of Wales has at least 2 more opportunities to improve services than services to be preserved.

An assessment of the amount of land inside and outside of the scheme which was either mitigating or mitigated for rainfall runoff / flood mitigation was calculated. The results suggests there is little difference between the land inside and outside of the Glastir scheme with respect to either mitigating or mitigated features. The values are 19% and 21% for land in and out of scheme for mitigating features and 19% and 17% for mitigated features respectively.

Ordination of spatial variation with environmental constraints indicated that only 3% of spatial variation in combined ecosystem service status can be explained by precipitation, temperature regime, elevation, slope and soil drainage and acidity. This indicates the importance of simulation of topology and topography when assessing condition of the relevant ecosystem services; for this reason spatially explicit modelling as applied in LUCI has significant benefits over simplified point combination of spatial data.

Opportunities to:

- Improve (reduce) N and P potential loss to freshwaters tend to be characterised by lower calcium carbonate ('lime') rank, higher maximum and minimum temperature, lower precipitation, lower elevation and gentler slopes.
- Improve carbon status tend to be characterised by higher lime rank, lower maximum and higher minimum temperature and gentler slopes.
- Improve erosion risk tend to be characterised by lower lime rank, lower maximum and minimum temperature, higher precipitation and steeper slopes.
- Improve Broadleaved woodland connectivity tend to be characterised by lower lime rank, higher maximum and minimum temperature and gentler slopes.
- Mitigate overland flow tend to be characterised by lower lime rank, higher maximum and minimum temperature, lower precipitation, lower elevation and gentler slopes. Low utilisation status tend to be characterised by higher lime rank, lower maximum and minimum temperature, higher precipitation, higher elevation and steeper slopes.

Testing of LUCI outputs has continued and suggests findings are robust for water flow, agriculture potential and current agriculture utilisation and nitrate export to rivers. As LUCI does not include point sources of phosphorus such as sewage works, further work is required to include these or mask them out from LUCI assessments for phosphorus assessments. Erosion and sediment delivery are not well represented by any models available at this time, and there is a need for further research to improve predictions in this area. Current assessment only includes the inherent structure of the landscape such as slope and water, so inclusion of land management such as tillage may improve simulation by LUCI in future, however this has not been a focus for model development. However, it should also be noted there is a lack of good quality national erosion data to test LUCI functionality for this service.

10.3 Methods

LUCI is a second generation extension and software implementation of the Polyscape framework described in Jackson *et al.* (2013). It is specifically tailored to investigate the cumulative impact of individual farm scale interventions within larger catchments, and its use in Year 1 of GMEP is described in Emmett *et al*., 2014. The major achievement for the LUCI modelling work within Year 1 of GMEP was its deployment over all of Wales. A number of individual service maps and associated tables were generated at 5x5m scale for the entire 20,600 km^2, the first ever deployment of an ecosystem service model with such fine spatial resolution at a national scale. Each map (and intermediate calculation) consisted of ~825 million "data" points. In this second year, we have consolidated on this, adjusting the setup and data handling and increasing automation of the "all-Wales" calculations to make the model more tractable for regular use. With these improved processes in place, we focused on verifying model integrity and identifying further development and research priorities through comparing results with national data and/or independent estimates, and exploring trade-offs and "win-win" opportunities for preservation of status quo or change within the landscape. Example outcomes from these verification exercises and trade-off analyses are described within this chapter.

Service	Description
P potential loss to freshwaters	Accumulation of P over the landscape, based on export coefficients for land use, and tracking of flow of water and nutrients over the landscape. This is classified into low, high and very high before being fed into trade off calculations.
N potential loss to freshwaters	Accumulation of N over the landscape, based on export coefficients for land use, and tracking of flow of water and nutrients over the landscape. This is classified into low, high and very high before being fed into trade off calculations.
Carbon Status	Status classification based on the amount of carbon present in biomass and soil, and whether this may be accumulating or decreasing under current land use. Sites which are sequestering, or high carbon and steady state are assigned as good. Sites which are low and not sequestering were assigned as moderate and sites losing or low carbon which are not sequestering are assigned as bad.
Erosion risk	Risk of erosion based on calculations of slope, flow accumulation and curvature
Broadleaved woodland connectivity	"Opportunity to improve" where existing habitat can be extended, based on cost distance for focal species to cross surrounding terrain – i.e. how far species from the habitat of interest are likely to travel. "good condition" for existing habitat and other protected habitats.
Flood mitigation class	"Opportunity to improve" where flow concentration is high or moderate. "good condition" for features which increase infiltration and reduce overland flow e.g. forest.
Potential agricultural utilisation	Level of agriculture that the land can support based on soil, slope and aspect
Current agricultural utilisation	Categorisation of current land use in terms of agricultural productivity
Relative agricultural utilisation	Difference between current and potential agricultural utilisation – i.e. a measure of how appropriate the current level of agricultural utilisation is

Table 10.3.1 *Description of LUCI model ecosystem service outputs used in this chapter.*

10.3.1 LUCI trade-off mapping approach

The ecosystem approach offers an opportunity to consider how adaptations in response to policy and other drivers might impact on multiple sectors. However, exploration of the interactions between these multiple sectors remains challenging. Although the mathematical theory of optimising management with respect to outcome values is well-developed, it is usually difficult to apply to agricultural landscapes in practice, particularly at scales meaningful for farm management decision making (sub-field to farm scale), where computational costs of robust optimisation methodologies become prohibitive. Often improving one ecosystem service will mean a deterioration in another, so a model needs to accommodate trade-offs and highlight potential win-win situations if it is to be a useful decision-support tool. The model outputs used for LUCI tradeoffs, as shown in Table 10.4.1.3 and figure 10.4.1.3 are; relative agricultural productivity, carbon status, Broadleaved woodland habitat connectivity, flood risk mitigation, erosion risk mitigation, reduction of N potential loss to freshwaters and reduction of P potential loss to freshwaters.

For agricultural productivity, carbon status, broadleaved woodland habitat connectivity and flood risk mitigation, the trade-off tool considers areas with opportunity to improve, areas with risk of deterioration, and areas where neither improvements or deterioration are likely to significant. For these services risk of deterioration is identified under the conditions stated in Table 10.3.1.1 and good conditions can be clearly defined and identified. Change in land use would be at high risk of damaging that good status. The trade-off tool also identifies priority areas where erosion could be reduced, and where N and P could be intercepted to preserve freshwater quality. It does not currently distinguish between areas where modification to existing use might have insignificant effects or risk deterioration of erosion risk and/or N and P impacts on freshwaters. This is because the distinction between “good” or “insignificant unimportant” status for these services cannot be defined with enough confidence to warrant assignment of a trade-off where there is potential to improve another service. It is particularly difficult to identify such “risk” for reduction of potential N and P loss to freshwaters, because this status reflects conditions in upslope areas as well as conditions at the site, a change at this point may not be detrimental to good provision for this service.

Service	Conditions for good status/risk of deterioration	Conditions for poor status/opportunity to improve
Relative agricultural productivity	Typical and near typical agricultural production	Land very unusually utilised (either unusually high utilisation or unusually low utilisation)
Carbon status	C stock high to very high and not losing, or gaining stock at high to moderate rate	Losing C at a moderate to rapid rate
Broadleaved woodland habitat connectivity	Existing habitat of interest or other priority habitat	Opportunity to extend existing habitat
Flood risk mitigation	Mitigating feature	Moderate to high flood concentration
Erosion risk mitigation	Not assigned – current trade off calculations target areas at risk (however sediment calculations assign good status to areas that trap sediment from high risk erosion lands).	Moderate to high erosion risk
Reduction of potential N loss to freshwaters	Not assigned; calculations target high risk areas only	High to very high concentration
Reduction of potential P loss to freshwaters	Not assigned; calculations target high risk areas only	High to very high concentration

Table 10.3.1.1 *Ecosystem service conditions for assignment of status as risk or opportunity for trade-offs.*

LUCI includes algorithms to examine trade-offs and co-benefits between the individual ecosystem services in a number of ways. They are primarily designed to highlight areas where interventions provide multiple benefits and areas where intervention is clearly undesirable because existing socioeconomic or ecological value is high (Jackson *et al*., 2013). For input into the trade-off mapping, each service (TSi) takes a value to indicate potential losses or gains with change in land use or management at that point. For agricultural productivity, carbon status, Broadleaved woodland habitat connectivity and flood risk mitigation; the value is assigned as -1, 0, or 1, where -1 indicates anticipated losses arising with change, 0 indicates no significant losses or gains associated with change, and 1 indicates gains ("wins") anticipated with some changes. For erosion risk mitigation and reduction of potential N and P loss to freshwaters; the value is assigned as 0, or 1, where 0 indicates no significant losses or gains associated with change, and 1 indicates gains ("wins") anticipated with some changes. Values of -1 for anticipated losses were not assigned to erosion N and P, even where condition is relatively good, for the reasons explained above.

Even with this coarse three-way categorisation of "win/loss" potential, the number of possible combinations is 3^N where N is the number of services being considered. This inflates rapidly as the number of services increase, as can be seen from the second to last row of Table 10.3.1.2 To simplify communication, LUCI initially highlights the summary combinations, categorising each cell in the landscape according to the overall number of wins, losses and "no significant impact" rather than by specific service combinations. These summary combinations inflate less rapidly (see last row of Table 10.3.1.2), but still quickly pose an issue for detailed analysis.

	Number of services being considered							
	2	3	4	5	6	7	8	N
Potential individual combinations	9	27	81	243	729	2187	6581	3^N
Potential summary combinations	6	10	15	21	28	36	45	$\sum_{i=1}^{N+1} i$

Table 10.3.1.2 *Number of possible combinations of trade-offs/co-benefits as services increase.*

Even after these simplifications, there remain an almost infinite number of options for taking them forward to numerical evaluation of trade-offs. Five mathematical representations are included in the current version of LUCI:
1= equal arithmetic (an unweighted additive approach),
2 = conservative (opportunities to improve are considered only where there is no risk of degradation to another service),
3 = standard (an "expert opinion", subjective balance between the equal arithmetic and conservative approach; somewhat weighting the importance of not degrading services above improving services while still allowing some degradation if major gains in improvement can be achieved),
4 = weighted arithmetic (a weighted additive approach),
5 = mixed conservative/weighted additive

For this report, which contains our first analysis of trade-offs and co-benefits at a national scale, we used the equally weighted additive option, implicitly treating all services as being of equal value. The generic equation defining the arithmetic multiple criteria opportunity mapping is:

$$NonCat\_OTS = \frac{\sum_{i=1}^{N} w_i TS_i}{\sum_{i=1}^{N} w_i} \quad ,$$ (Equation1)

where N represents the number of services being analysed and w_i represents the weights assigned to each service. All values lie between -1 and 1. Maximum potential for change is indicated by a value of 1, while maximum prioritisation for the status quo is indicated by a value of -1. In the case of equal weighting between all services, as assumed in this study, Equation 1 simplifies to:

$$NonCat\_OTS = \frac{\sum_{i=1}^{N} TS_i}{N}$$ (Equation 2)

In "English", another way to think of Equation 2 is

$$NonCat\_OTS = \frac{[number\_of\_wins - number\_of\_losses]}{[number\_of\_wins + number\_of\_losses + number\_of\_"no\_change"]}$$

The categorisation for either Equation 1 or 2 then proceeds as follows to define values for mapping:

if	*NonCat_OTS* > TCT1,	High change opportunity
elseif	*NonCat_OTS* ϵ [TCT2, TCT1],	Moderate change opportunity
elseif	*NonCat_OTS* ϵ TCT3,TCT2],	Negligible opportunity or near-balanced trade-offs
elseif	*NonCat_OTS* ϵ TCT4,TCT3]	Moderate preservation opportunity
elseif	*NonCat_OTS* < TCT4,	High preservation opportunity

In this application (which uses the default LUCI thresholds), *TC1* = 0.6, *TC2* = 0.3, *TC3* = -0.3 and *TC4* = -0.6. Synergies and trade-offs in existing and potential service provision are then identified. These trade-off maps offer a means for recognising the value of existing landscape features and targeting and prioritising opportunities for landscape change by being explicit about where trade-offs and synergies between these services occur within the landscape.

10.4 Results

10.4.1 Ecosystem services condition, opportunities to improve, and trade-offs or co-benefits between services

Ecosystem services condition, opportunities to improve, and trade-offs or co-benefits between services were identified, based on combining spatial data on model classifications of ecosystem service condition as high existing service, negligible existing or potential service, or opportunities to improve existing service provision for reduction of N and P potential loss to freshwaters, status of carbon in soil and biomass, and erosion risk. This differs from the default LUCI trade off calculations and mapping, which do not consider potential risk of loss of good condition for reduction of N and P potential loss to freshwaters, and erosion risk, however it is interesting to consider the areas which might be affected if these trade-offs were considered.

For habitat connectivity, separate consideration was given to locations with potential to expand existing Broadleaved woodland, and locations occupied by other priority habitat, since these may be protected from land use change or other interventions. For flood mitigation, it must be remembered that not all locations classified as "non-mitigated" represent opportunities to reduce flood risk;

rather they represent opportunities to reduce contributions from those areas to stream flow in high flow conditions. Interventions which increase infiltration and slow transit of water into the main watercourse will act to stabilise flow levels, increasing base flow and reducing flow peaks, and associated flood risk, following precipitation events. However where interventions increase evapotranspiration losses significantly, the reduction in volume of water reaching the stream may be detrimental to flow regime if low flow or over abstraction are more significant issues in that catchment. For agricultural land utilisation, assessments were based on whether current production was classified as high, moderate, or low, since it is desirable to improve ecosystem service provision without significantly impacting agricultural productivity where possible. This differs from the default LUCI trade off calculations and mapping, which instead consider relative agricultural productivity, i.e. whether the land is under an appropriate level of production for the site.

Calculations have been made on the spatial data to identify for each ecosystem service the total area with good provision, total area with opportunity to improve, and area with opportunity to improve without risk to existing services in good condition; these numbers are shown in Table 10.4.1.1. Further calculations were then performed for each ecosystem service to identify where opportunities to improve ecosystem services coincide spatially with good existing condition for each other ecosystem service; these numbers are shown in Table 10.4.1.2. Finally, calculations were performed for each ecosystem service pair to identify where both have opportunities to improve; these numbers are shown in Table 10.4.1.3.

Service	**Good existing service provision**	**Moderate existing service provision**	**Opportunity to improve service provision (A)**	**Affected by trade-off with another service (B)**	**Opportunity to improve without risk to existing good status for another service (A-B)**
P potential loss to freshwaters	19169		1263	1226	37
N potential loss to freshwaters	15201		5231	5127	**<u>104</u>**
Carbon Status	2830	6648	**<u>10508</u>**	10498	10
	Existing low risk	Existing moderate risk	Opportunity to reduce risk	Affected by trade-off with another service	Opportunity to improve without risk to existing good status for another service
Erosion risk	18608	1610	220	211	9
	Good existing service provision	Other priority habitat	Opportunity to extend habitat	Affected by trade-off with another service	Opportunity to extend, without risk to existing good status for another service
Broadleaved woodland connectivity	1224	1565	**<u>4595</u>**	4501	**<u>94</u>**
	Good existing service provision		Non-mitigated features	Affected by trade-off with another service	Opportunity to improve without risk to existing good status for another service
Flood mitigation class	7785		12654	12333	**<u>321</u>**
	High production	Moderate production	Low production	Affected by trade-off with another service	Opportunity to increase production without risk to existing good status for another service
Current agricultural utilisation	10106	5059	4387	4290	**<u>97</u>**

Table 10.4.1.1 *Existing ecosystem service provision, opportunities to improve, and trade-offs where these opportunities to improve coincide with other ecosystem services in good condition. All areas given in km^2. Figures commented on in text are shown in bold and underlined to help the reader navigate the tables. Reduction of N and P potential loss to freshwaters, and erosion risk have among the highest numbers for "Good existing service provision" under this approach, and would thus result in significant areas of trade-offs if this approach had been adopted in the LUCI default trade-off tool.*

Table 10.4.1.2 indicates that significant areas have opportunity to improve carbon (C) status (10508km^2), however for the vast majority of these sites, there are other services in good condition, so care must be taken to avoid detrimental effects if interventions are targeted at improving C status. Table 10.4.1.2 indicates that many of these trade-offs are with priority habitats (7488 km^2) (largely heather dominated grasslands), agricultural utilisation (5424 km^2) erosion risk (9693 km^2), and nitrogen (N) (7731 km^2) and phosphorus (P) (9834 km^2) potential loss to freshwaters. It is likely that changes to improve C status would not increase erosion risk, or N and P potential loss to freshwaters (which may help to justify the exclusion of "good status" for these services in the LUCI default trade-offs), however the need to protect priority habitats, and socioeconomic value of agricultural production may reduce potential to achieve carbon status improvements.

N potential loss to freshwaters has reasonable opportunities (104 km^2) to improve (reduce) without risk of damaging other ES or agricultural productivity. Significant proportions of the 5231 km^2 of sites with opportunity to reduce N potential loss to freshwaters also have opportunities to reduce P potential loss to freshwaters (1228 km^2), and improve C status (2777 km^2), Broadleaved woodland habitat connectivity (1038 km^2) and mitigation of overland flow which may contribute to flood mitigation (3955 km^2), as indicated in Table 10.4.1.3

Table 10.4.1.1 indicates that over 321km^2 were classified as non-mitigated in terms of runoff, and had no other ecosystem services in good condition, which may indicate significant potential for interventions to reduce flood risk, without damaging other ES or agricultural productivity. However depending on flow regimes not all of these non-mitigated features currently create flood risk, hence further assessment of these opportunities is necessary.

Locations with low agricultural productivity that are not in good condition for other ES were mapped as over 97 km^2 as can be seen in Table 10.4.1.1. Whilst there may be potential to increase agricultural productivity in these locations, land may be less suitable for agriculture, and interventions to improve other ES may be more appropriate.

Service with opportunity to improve	Area with opportunity to improve service provision (km²)	Area coinciding with good existing provision for other (specified) ecosystem service (km²)							
		P accumulation load	N accumulation load	Carbon Status	Erosion risk	Broadleaved woodland connectivity	Other priority habitat	Flood mitigation class	Current utilisation
P potential loss to freshwaters	1263	X	14	65	2260	59	958	146	858
N potential loss to freshwaters	5231	3915	X	232	4559	205	3900	1187	3936
Carbon Status	10508	**<u>9834</u>**	**<u>7731</u>**	x	**<u>9693</u>**	637	**<u>7488</u>**	3264	**<u>5424</u>**
Erosion risk	220	156	117	62	x	51	97	115	48
Broadleaved woodland connectivity	4595	4292	3479	453	3993	x	x	2162	0
Flood mitigation class	12654	11246	8387	81	11422	0	9988	x	7869
Current agricultural utilisation	4387	4211	4027	2723	3715	2714	1017	4171	x

Table 10.4.1.2 *Opportunities to improve ecosystem services often coincide spatially with other ecosystems in good existing condition, leading to trade-offs, in the sense that the target ecosystem service cannot be improved without risk of detriment to existing service provision. This table indicates for each ecosystem service the area with opportunities to improve, and how much of this coincides with existing good condition for each other ecosystem service. All areas given in km². Figures commented on in text are shown in bold and underlined to help the reader navigate the tables.*

Win-wins: areas with opportunities to improve both ecosystem services	P potential loss to freshwaters	N potential loss to freshwaters	Carbon Status	Erosion risk	Broadleaved woodland connectivity	Flood mitigation class	Current utilisation
P potential loss to freshwaters	x	1228	674	61	225	1096	79
N potential loss to freshwaters	**<u>1228</u>**	X	**<u>2777</u>**	100	**<u>1038</u>**	**<u>3955</u>**	263
Carbon Status	674	2777	x	88	**<u>2382</u>**	7244	1312
Erosion risk	61	100	88	x	70	103	84
Broadleaved woodland connectivity	225	1038	2382	70	x	2355	560
Flood mitigation class	1096	3955	7244	103	2355	x	119
Current agricultural utilisation	79	263	1312	84	560	119	x

Table 10.4.1.3 *Opportunities to improve ecosystem services may coincide spatially with other ecosystem services with opportunity to improve, leading to "win-wins". This table indicates for each ecosystem service the area of opportunities to improve which coincide with opportunity to improve for each other ecosystem service: i.e. for each pair of ecosystem services, what area has*

opportunities to improve both. All areas given in km². Figures commented on in text are shown in bold and underlined to help the reader navigate the tables.

Opportunity to expand Broadleaved woodland without damaging agricultural productivity or other ES was mapped over 94 km² as shown in Table 10.4.1.1., and this habitat expansion is likely to also benefit carbon status and water quality, since of the 4595 km² total area identified for potential habitat expansion 2382 km² have opportunity to improve C status and 1038 km² have opportunity to reduce potential N loss to freshwaters, as shown in Table 10.4.1.3. Looking at co-location of opportunities to improve ecosystem services for carbon, nitrogen and phosphorus and expand Broadleaved woodland in Figure 10.4.1.1 indicates that areas with co-benefits for habitat expansion, C and N do not always coincide; although a significant proportion of the country was identified as having opportunities for improvement in two services, very few had opportunities for three; these are only visible when smaller areas are examined as in Figure 10.4.1.2. Large areas have more opportunities to improve than services with existing good status; the output table indicates that for this comparison, these "win-wins" account for 67% of Wales.

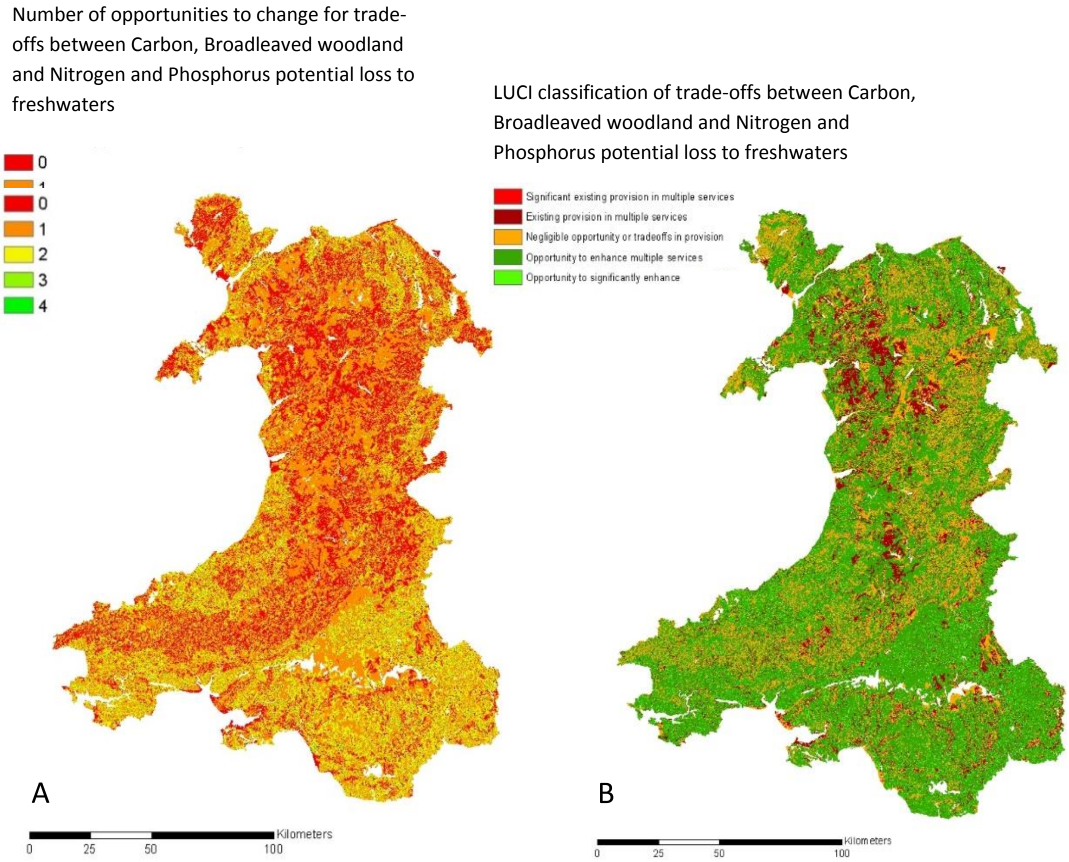

Figure 10.4.1.1 *Trade-offs between ecosystem services for carbon, nitrogen, phosphorus and Broadleaved woodland. A. shows number of opportunities to improve; note values of 3 and 4 (greens) do occur but are barely visible at national scale. B. maps opportunities and trade-offs, and indicates that although most sites shown in A. only have opportunity to improve one or two services, large areas have more opportunities to improve than services with existing good status; the output table indicates that for this comparison, these "win-wins" account for 67% of Wales.*

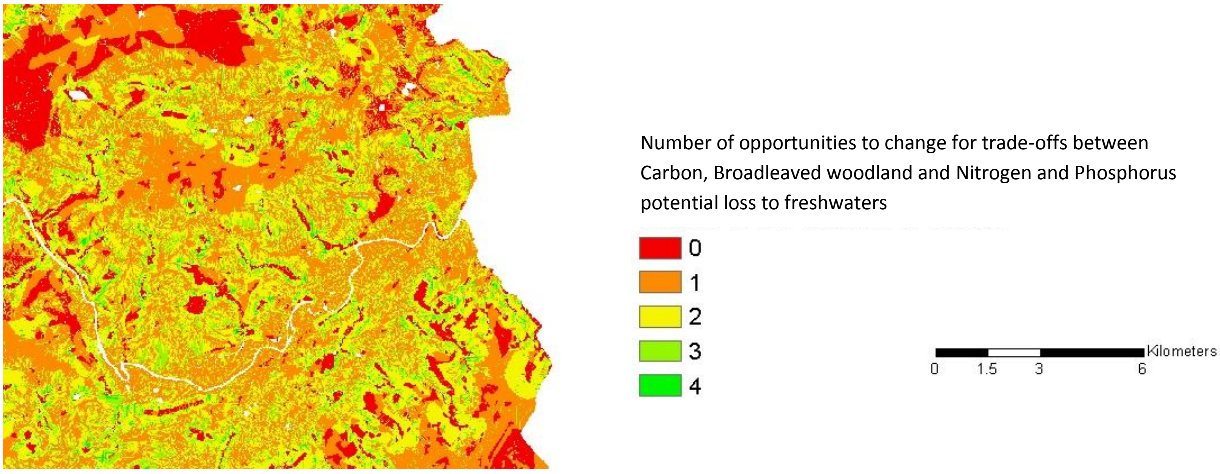

Figure 10.4.1.2 *Opportunities to improve ecosystem services for carbon, nitrogen and phosphorus or expand Broadleaved woodland for a small area in south Wales*

To explore this issue further, calculations have been performed on all outputs to identify where there are trade-offs and win-wins across all 7 ecosystem services considered, i.e. for combinations of 1-7 ecosystem services, the total area with opportunity to improve the stated number of services, and a breakdown of which services are in good condition and which have opportunity to improve for the relevant area. For example, as indicated in Table 10.4.1.3., 36 km^2 have opportunities to improve 6 of the 7 modelled ecosystem services; all of this area has opportunity to improve (reduce) potential loss of N to freshwaters, whereas 16 km^2 have good existing provision of agricultural productivity.

Looking at co-location of opportunities to improve ecosystem services for all 7 services Figure 10.4.1.3 indicates that ca. 10% has existing multiple service provision whilst almost 28% of Wales has at least 2 more opportunities to improve services than services to be preserved.

No. Of services with opportunities to improve		Opportunities to improve service (km^2)							Service already in good condition(km^2)			
	total	AGP	CAR	HAB	FLO	ERO	NIT	PHO	AGP	CAR	HAB	FLO
7	1	1	1	1	1	1	1	1	0	0	0	0
6	**36**	15	35	28	35	32	**36**	33	**16**	0	0	<1
5	292	93	269	147	282	144	291	236	157	0.5	<1	1
4	1154	262	968	412	1070	273	1080	552	730	4	1	5
3	2783	270	2083	924	2322	432	1981	336	2057	1	0	18
2	1302	348	1059	357	606	85	148	1	0	0	0	0
1	0	0	0	0	0	0	0	0	0	0	0	0

Table 10.4.1.3 *Breakdown of areas with more opportunities to improve services than services to be preserved, according to LUCI default trade off tool. Where AGP= relative agricultural productivity, CAR= carbon status, HAB= Broadleaved woodland habitat connectivity, FLO=flood risk mitigation, ERO= erosion risk mitigation, NIT= N potential loss to freshwaters and PHO= P potential loss to freshwaters. Figures commented on in text are shown in bold and underlined to help the reader navigate the tables. Note declining numbers as more services are considered from 3 to 7. ERO, NIT and PHO are not listed under "Service already in good condition" because the LUCI trade of tool does not assign trade-offs for such sites.*

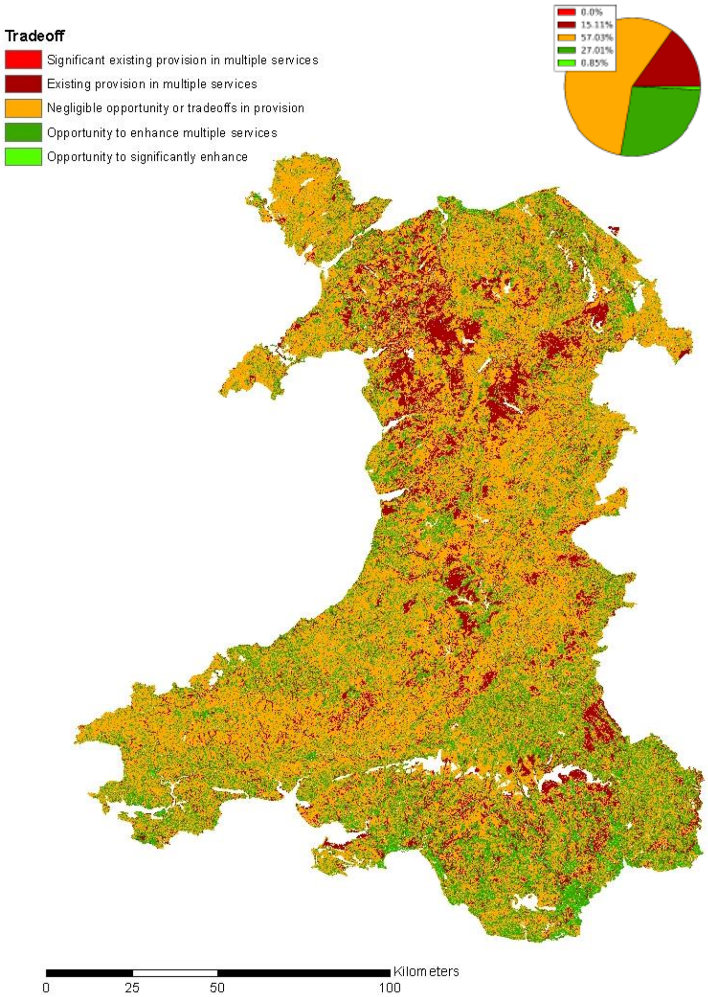

Figure 10.4.1.3 *Outcomes for trade-offs between relative agricultural utilisation, carbon status, nitrogen and phosphorus status, erosion status, Broadleaved woodland connectivity and flood mitigation ecosystem services; almost 28% of Wales has at least 2 more opportunities to improve services than services to be preserved. This map was produced using LUCI default trade off mapping approach, applying equal weighting to all services (as described in Section 10.1.3).*

10.4.2 What determines ecosystem service distribution across the landscape?

Figure 10.4.2.1 shows an ordination of spatial variation in combined ecosystem service status across the 7 services considered; further ordination analysis with environmental constraints applied, indicated that only 3% of spatial variation in combined ecosystem service status can be explained by precipitation, temperature regime, elevation, slope and soil drainage and acidity. This indicates the importance of simulation of topology and topography when assessing condition of the relevant ecosystem services; for this reason spatially explicit modelling as applied in LUCI has significant benefits over simplified point combination of spatial data. Around 40% of variation in combined ecosystem service status can be attributed to land use classification, however this artificial constraint was not considered in the environmental typologies analysis. The remaining 60% requires explicit simulation of spatial relationships between land types, taking into account topography and location of watercourse in order to simulate ecosystem service condition.

Nonetheless some trends with environmental variables can be observed for the ecosystem services assessed. Opportunities to reduce N and P potential loss to freshwater tend to be characterised by lower CACO3 rank, higher maximum and minimum temperature, lower precipitation, lower elevation and gentler slopes. Opportunities to improve carbon status tend to be characterised by higher CACO3 rank, lower maximum and higher minimum temperature and gentler slopes. Opportunities to improve erosion risk tend to be characterised by lower CACO3 rank, lower maximum and minimum temperature, higher precipitation and steeper slopes. Opportunities to improve Broadleaved woodland connectivity tend to be characterised by lower CACO3 rank, higher maximum and minimum temperature and gentler slopes. Opportunities to mitigate overland flow tend to be characterised by lower CACO3 rank, higher maximum and minimum temperature, lower precipitation, lower elevation and gentler slopes. Low utilisation status tend to be characterised by higher CACO3 rank, lower maximum and minimum temperature, higher precipitation, higher elevation and steeper slopes.

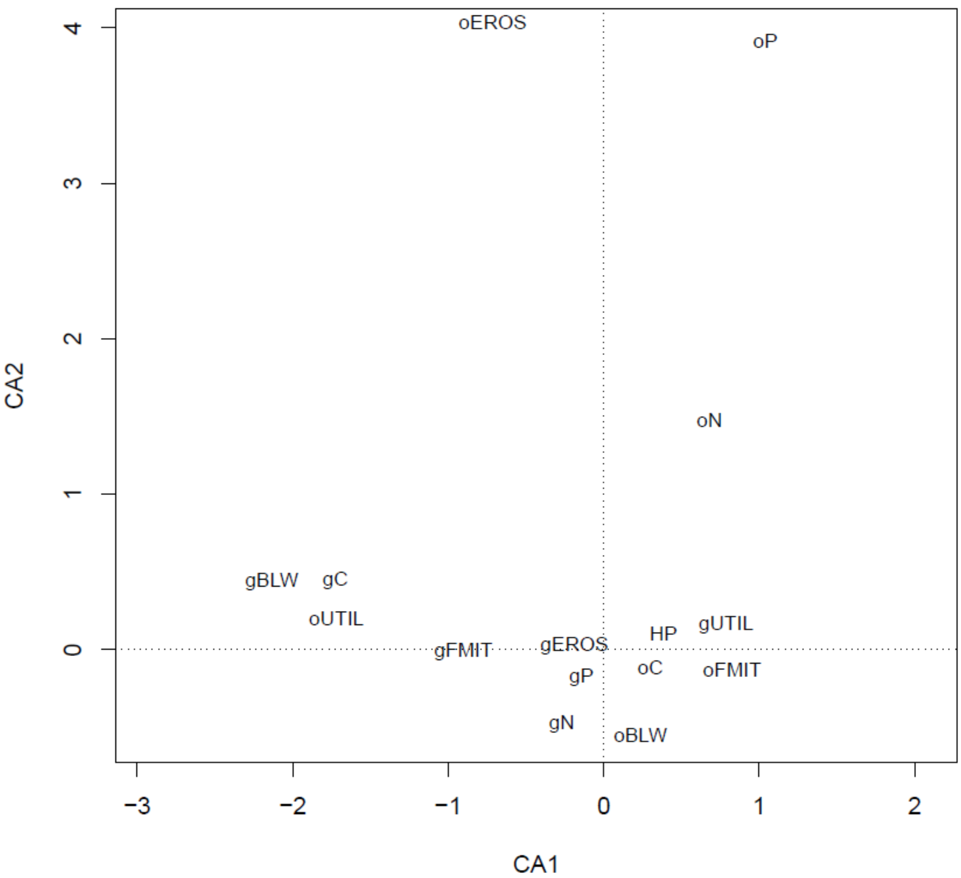

Figure 10.4.2.1 *Ordination of Ecosystem service condition*
Where: gUTIL = high current agricultural utilisation, gEROS = low erosion risk status, gP = low P potential loss to freshwater , gN = low N potential loss to freshwater , gFMIT = Flow accumulation mitigation or mitigated feature, gC = good C status, gBLW = Broadleaved woodland, HP = other priority habitat, oUTIL = low current agricultural utilisation, oEROS = opportunity to improve erosion status, oP = opportunity to reduce potential P loss to freshwater, oN = opportunity to reduce potential N loss to freshwater, oFMIT = No mitigation of overland flow accumulation, oC = opportunity to improve C status and oBLW = opportunity to expand Broadleaved woodland

10.5 Is land inside the Glastir scheme providing better flood mitigation protection to that outside the scheme?

An assessment of the amount of land inside and outside of the scheme was calculated.

Wales	Wales (ha)	% of Wales	Land in Glastir (ha)	% of land in Glastir	Land outside of Glastir (ha)	% of land outside of Glastir
Mitigating features	422499	20	114366	19	308134	21
Mitigated features	355983	17	112955	19	243028	17
Non-mitigated features	1265396	61	374980	62	890415	61
Water bodies	31268	2	5875	1	25393	2
Total	2075146		608176	100	1466970	100

Table 10.5.1 *Breakdown on land in and out of Glastir according to mitigation status for overland flow of water, N and P. This is a conservative estimate, and values are expected to increase slightly with Inclusion of the HOST dataset to account for mitigation from* well drained soils.

The results suggests there is little difference between the land inside and outside of the Glastir scheme with respect to either mitigating or mitigated features. The values are 19% and 21% for land in and out of scheme for mitigating features and 19% and 17% for mitigated features. This provides a baseline for future reporting as Glastir options are implemented.

10.6 Testing LUCI Model performance

GMEP has an ongoing programme for testing LUCI and its outputs. Here we present some latest assessments of model output.

Agricultural utilisation has been mapped across Wales using the LUCI (Land Utilisation & Capability Index) model according to soil type data from Cranfield University (NSRI) and land cover data collected in 2007 by the Centre for Ecology and Hydrology. The model calculates predicted optimal agricultural utilisation based on soil type, using assigned values of fertility and waterlogging (yes, no or seasonal) and topographic data, using calculated values for aspect slope and elevation. Current agricultural utilisation has been mapped according to the land cover data, ranking land use from highest productivity to lowest: Arable; Improved grassland; Unimproved grassland; Woodland and heath; Bog sand and rock. A weighting was applied to account for the relative suitability of Welsh farmland for intensive agriculture compared to optimal conditions for intensive agriculture; this weighting appears to be appropriate since over 75% of land was identified as having predicted usage from comparison of current and optimal usage.

The model also performs well when compared to other national level datasets of land quality and land use. For example Figure 10.6.1.1 indicates that predicted optimal utilisation (calculated from NSRI soil type data) correlates with Defra Agricultural Land Classification values which rank land from good (1) to poor (5). High or very high production is simulated for areas of land which are only in land class 3 or 4, due to the weighting applied in the model to account for the majority of Wales being in land classes 3-5. By taking this into account, the model is able to simulate optimal and relative utilisation of land in the context of overall availability of suitable land for agriculture in Wales.

10.6.1. LUCI model validation work

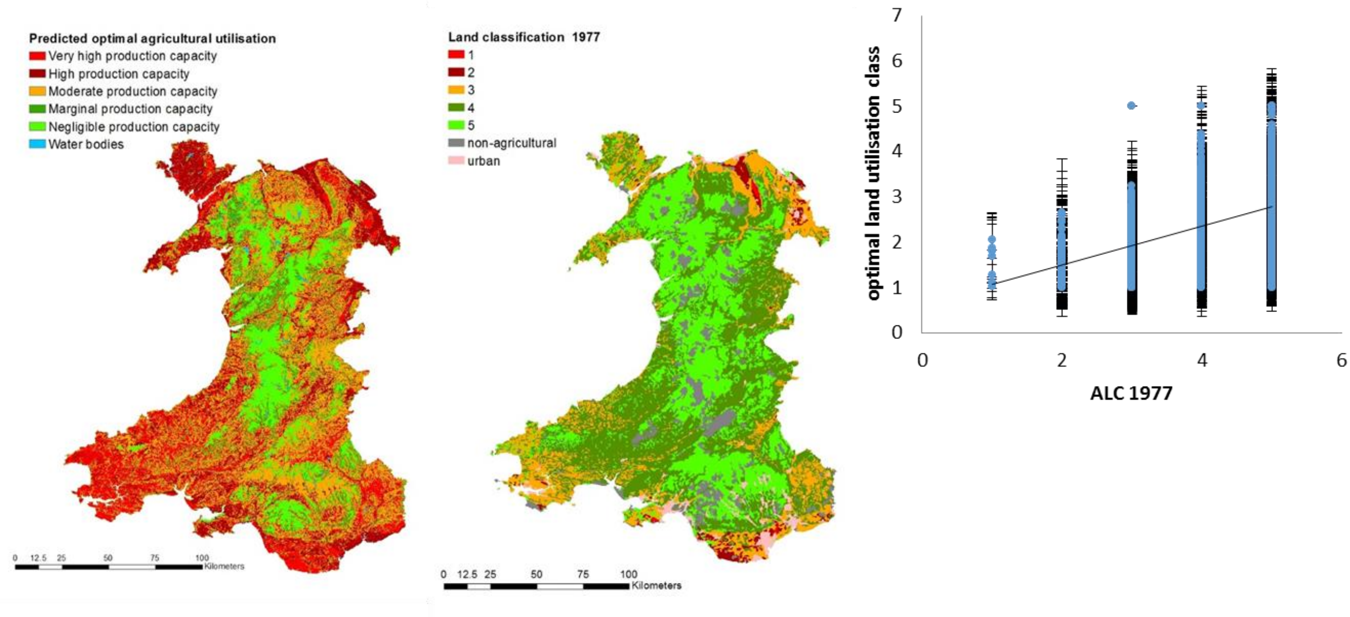

Figure 10.6.1.1 *Comparison of LUCI simulated 'optimal' agricultural land utilisation with Defra Agricultural Land Classification (ALC) values*

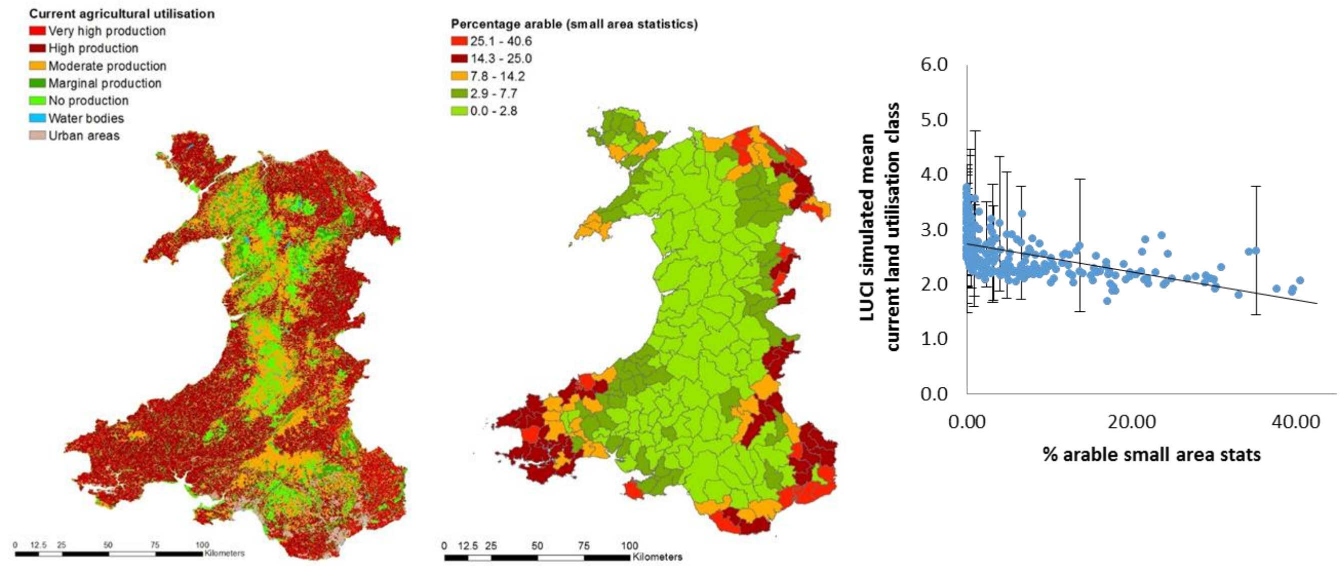

Figure 10.6.1.2 *Comparison of LUCI simulated 'current' agricultural utilisation with current area of arable land. LUCI scores high production land by a score of 1.*

Figure 10.6.1.2 indicates a good relationship between current agricultural utilisation (calculated from CEH 2007 land class data) and Defra Small Area Agricultural Census data, although the comparison is slightly limited by the fact that LUCI assigns high agricultural utilisation for intensively managed grassland, however data were not available to include in the comparison from the Defra agricultural survey.

The LUCI (Land Utilisation & Capability Index) model calculates flow over the landscape using GIS functions for calculating flow direction and accumulating water through the landscape through use of flow accumulation routines modified to account for spatial differences in rainfall, evaporation and soil properties. In these results, spatial data on precipitation and evapotranspiration were provided by the Met Office and input to LUCI as the annual average over 30 and ~50 year periods respectively. “Mitigating features” which prevent the movement of water downslope, such as woodland, swamp, bog and marsh are identified from land use data; in this case land cover data collected in 2007 by the Centre for Ecology and Hydrology. Flow from areas which route through these mitigating land use features are considered to be mitigated, i.e. water does not travel to the watercourse as overland or other rapid flow. Areas of well drained soils may also provide this type of mitigation, and further work utilising HOST data is expected to reveal a slight increase in mitigated area.

The model performs well at simulating annual average stream flow across Wales; modelled values are shown in Figure 10.6.1.3 plotted against the mean measurements taken at National River Flow Archive stations. NRFA station means are taken over the full recording period for that station (with start dates varying from 1879 to 1995), whereas modelled values are based on precipitation averages for 1961-1990 and estimated actual evapotranspiration values for 1961-2012. Note that the LUCI model for Wales has been set up over the extent of the country but not beyond; it therefore does not currently account for transboundary river crossings between England and Wales. Flow out to England is not conserved when the river returns to Wales, nor is additional input from England accounted for. As a result, the model significantly underestimates flow at NRFA stations on rivers which cross the border. Additional data for these transboundary catchments have been requested from the Welsh Government to allow the river border crossings to be accounted for in future work.

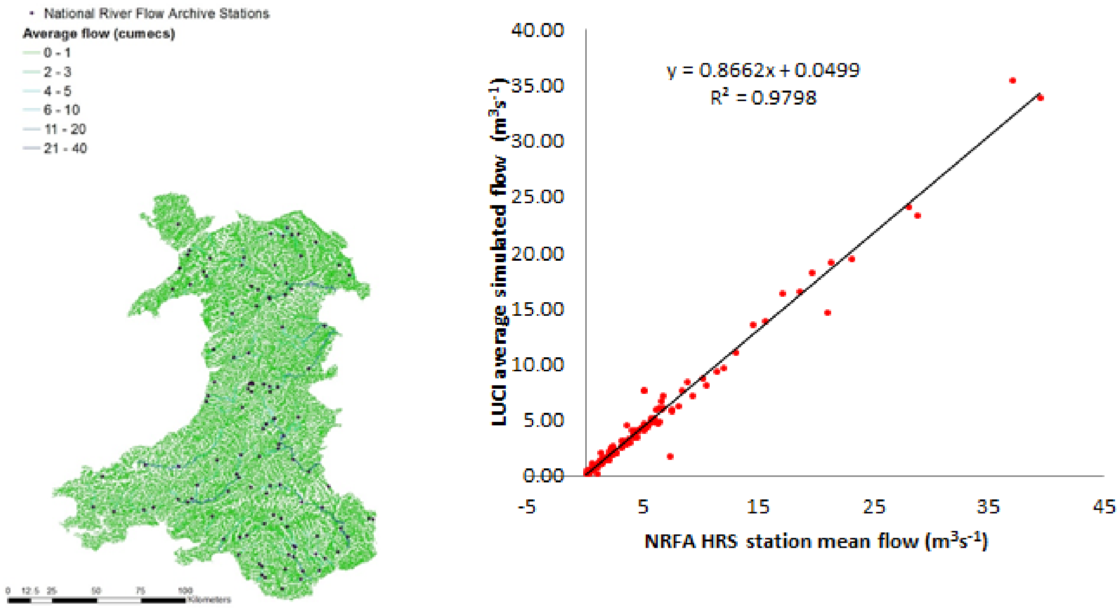

Figure 10.6.1.3 *Comparison of LUCI simulated annual average flow with NRFA mean flows*

The LUCI (Land Utilisation & Capability Index) model estimates nitrogen loading contributed at individual points in the landscape based on land cover, but additionally taking into account stocking rate and fertiliser input. Accumulated nitrogen and phosphorus loading is calculated by combining this data layer with a flow direction layer calculated from topography. Nutrient flow accumulation for near surface flow is calculated by weighting spatial data on flow direction by the appropriate nutrient export coefficients, and a factor for the solubility of nitrogen. “Mitigating features” which prevent the movement of water downslope, such as woodland, swamp, bog and marsh are identified from land use data. Later work to include the HOST dataset to account for mitigation from well drained soils may improve performance of this model component. For overland flow, spatial location of these mitigating features is used to remove areas which are not connected to the stream from the flow direction data layer, and then for the remaining areas flow direction is weighted by the appropriate export coefficients. The model was run using land cover data collected in 2007 by the Centre for Ecology and Hydrology to establish a baseline distribution of nitrogen and phosphorus loading generating and mitigating land, and in-stream concentrations. The output from this is simulated values of spatially distributed annual mean stream concentrations of dissolved nitrogen and dissolved phosphorus in the DEM-defined Welsh stream network.

These simulations may be compared with measured values of water quality to assess the performance of the LUCI model. Field data on total in stream P and N concentrations were not available on national scale for direct comparison with LUCI model output. Comparisons between modelled total P and measured soluble reactive P, and likewise between modelled total N and measured reactive soluble N should not be considered absolute, but are nonetheless indicative of model performance. These data were collected by NRW and formerly the EA in their routine monitoring, and are held by CEH in the Water Information Management Solution (WIMS) database. We have extracted mean concentrations for the year 2007 from the database, amounting to 834 sites for TON and 775 sites for SRP. Typically these individual means are based on twelve monthly samples, though the number may vary between sites.

As previously noted, the current LUCI setup does not consider flows into Wales from England, and therefore does not currently account for the effects of transboundary river crossings between England and Wales. The rivers Wye and Dee in their lower reaches, in particular, cross between the two countries. Where, for example, the Dee renters Wales, LUCI does not recognise it as the same river that left Wales, but as a new river. The concentrations in this “new” river are then estimated from the local land use characteristics, not accounting for the true upstream contribution from upland Wales. This tends to give overestimation of nutrient concentrations by LUCI. There are a small number of examples of such sites.

Having collocated simulation and measurement river cells, we can plot values against each other, as shown in Figure 10.6.1.4 and Figure 10.6.1.5 using a logarithmic scale. For nitrogen an unconstrained straight-line fit gives the following statistics: intercept 0.15; se 0.02; slope 1.03 se 0.02; r^2 0.72. These figures indicate a slight upward bias in the simulated nitrogen concentrations. These can partly be attributed to the transboundary phenomenon alluded to. For phosphorus, the equivalent model gives intercept -2.11 se 0.12; slope 0.6 se 0.04; r^2 0.26. These statistics reflect the notable upward bias in the simulated values compared to the measured, which is apparent from Figure 10.6.1.5. Simulated values are approximately half the measured values. Here it should be borne in mind that LUCI simulates only diffuse sources of phosphorus, and it is known that approximately half of the phosphorus in rivers is from point sources (although this proportion is declining). This suggests that once LUCI has been adapted to take account of point sources of phosphorus, its simulation performance should approximate its performance for nitrogen.

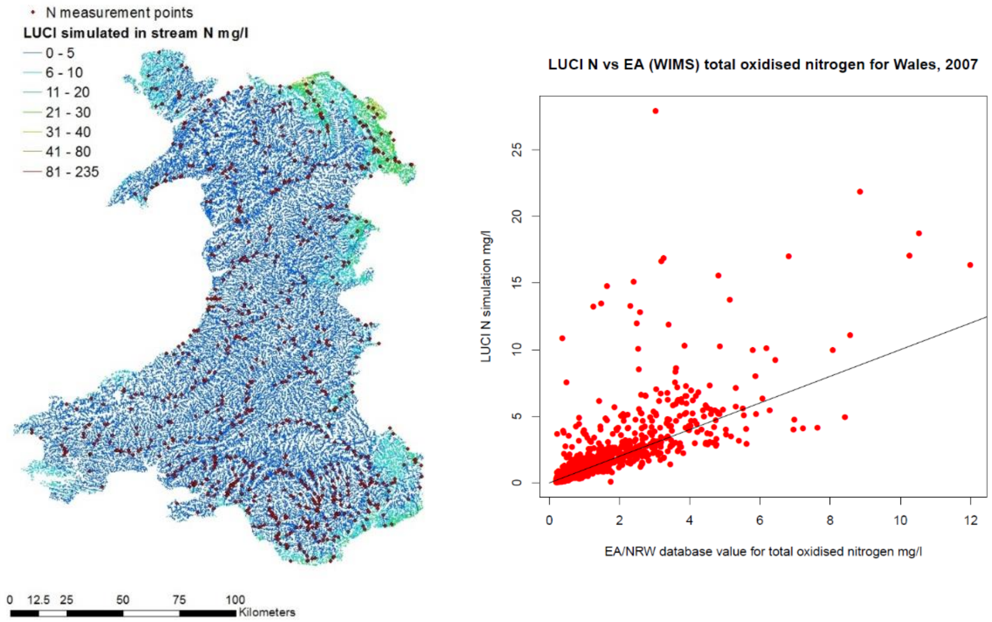

Figure 10.6.1.4 *Comparison of LUCI simulated in-stream total N concentrations attributed to diffuse sources, based on 2007 land use and long term annual averages for effective precipitation, versus EA (WIMS) measured total oxidised nitrogen annual average over 2007.*

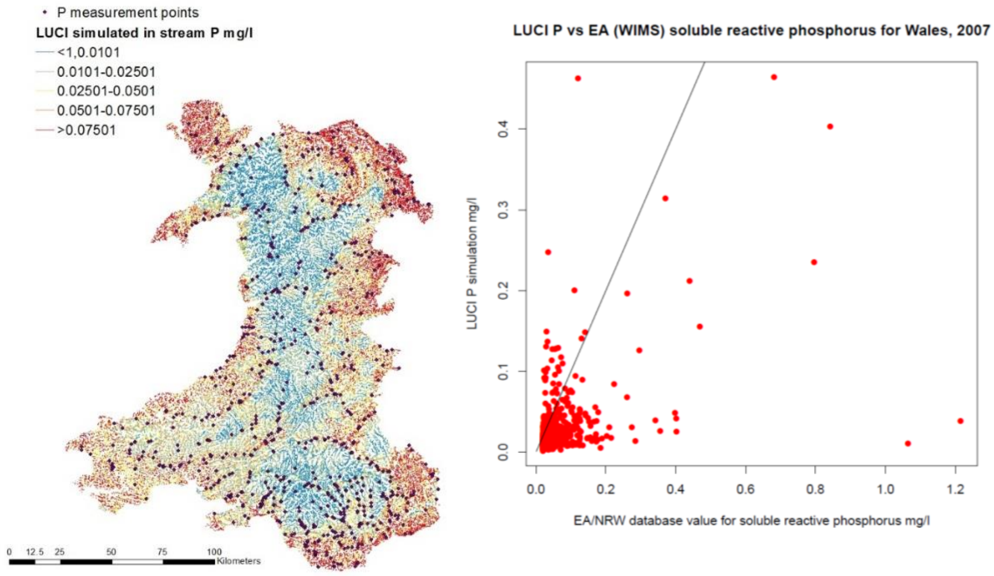

Figure 10.6.1.5 *Comparison of LUCI simulated long-term annual average in-stream total P concentration attributed to diffuse sources, based on 2007 land use and long term annual averages for effective precipitation, versus measured EA (WIMS) soluble reactive P annual average over 2007.*

10.7 LUCI model progress and anticipated developments for GMEP year 3 reporting

In future years LUCI will provide metrics for Glastir Outcome reporting for the change in % of land mitigated with respect to rainfall runoff / flood mitigated due to Glastir options.
Testing of the LUCI model will continue with respect to both ecosystem service delivery but also tested for outcome of land management interventions.

As part of both Year 2 and Year 3 work, we have also made significant progress on deploying a web-mapping service appropriate for Welsh catchments, and setting up for more temporal /event reporting from LUCI over Wales. Unfortunately we are unable to report or finalise testing due to data licensing issues. These are being addressed, and we will be reporting on this for Year 3.
More generally, LUCI development has been progressing through other projects, outcomes from which are all becoming available for use with the GMEP work. Changes of particular relevance for GMEP are:

- A new "native to LUCI" habitat and vegetation classification system is being introduced, allowing a wide variety of habitats, land cover and condition to be considered. This replaces the original system where exploration of impacts of management interventions or updates to data were somewhat restricted by the specific input habitat or vegetation dataset used.
- There is a significant project underway in New Zealand funding improvements to on-farm detail within LUCI, with a particular focus on how small scale interventions or changes in management practices modify export of water, sediment, nitrogen and phosphorus to streams. Many of these will translate directly to supporting more detail on Glastir options.
- LUCI is now formally version controlled so code changes/issues can be easily tracked, using the established "github" repository system. Results reported in this chapter are from LUCI v0.4
- Funding from the NERC INNOVATE funding stream has been won together with York University to develop methods for increasing the transparency and uncertainty level of the evidence base for users of ecosystem service models with LUCI as one of those test models.